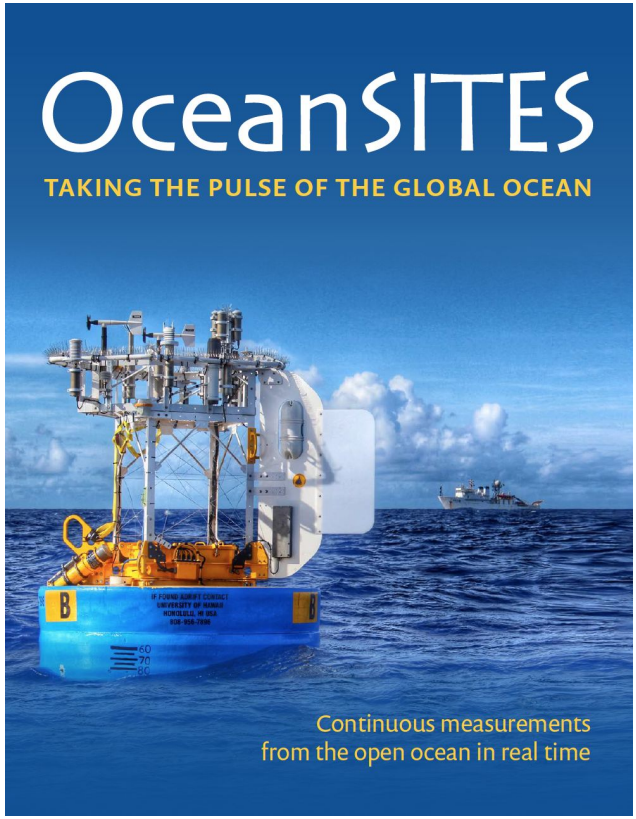
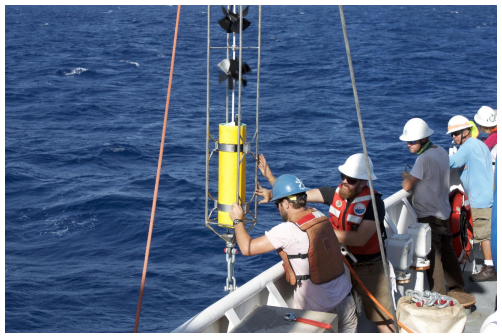
Global Ocean Monitoring and Observing
NATIONAL OCEANIC & ATMOSPHERIC ADMINISTRATION

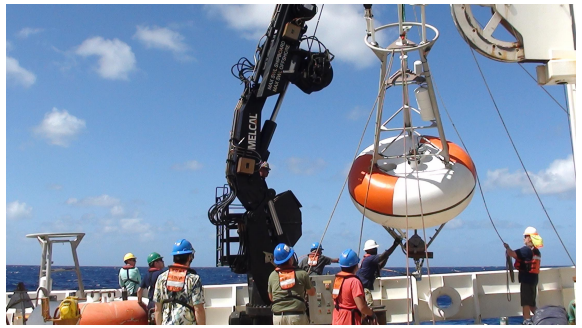


OceanSITES

Jim Todd
NOAA/OAR/GOMO

OceanSITES
Taking the pulse of the global ocean

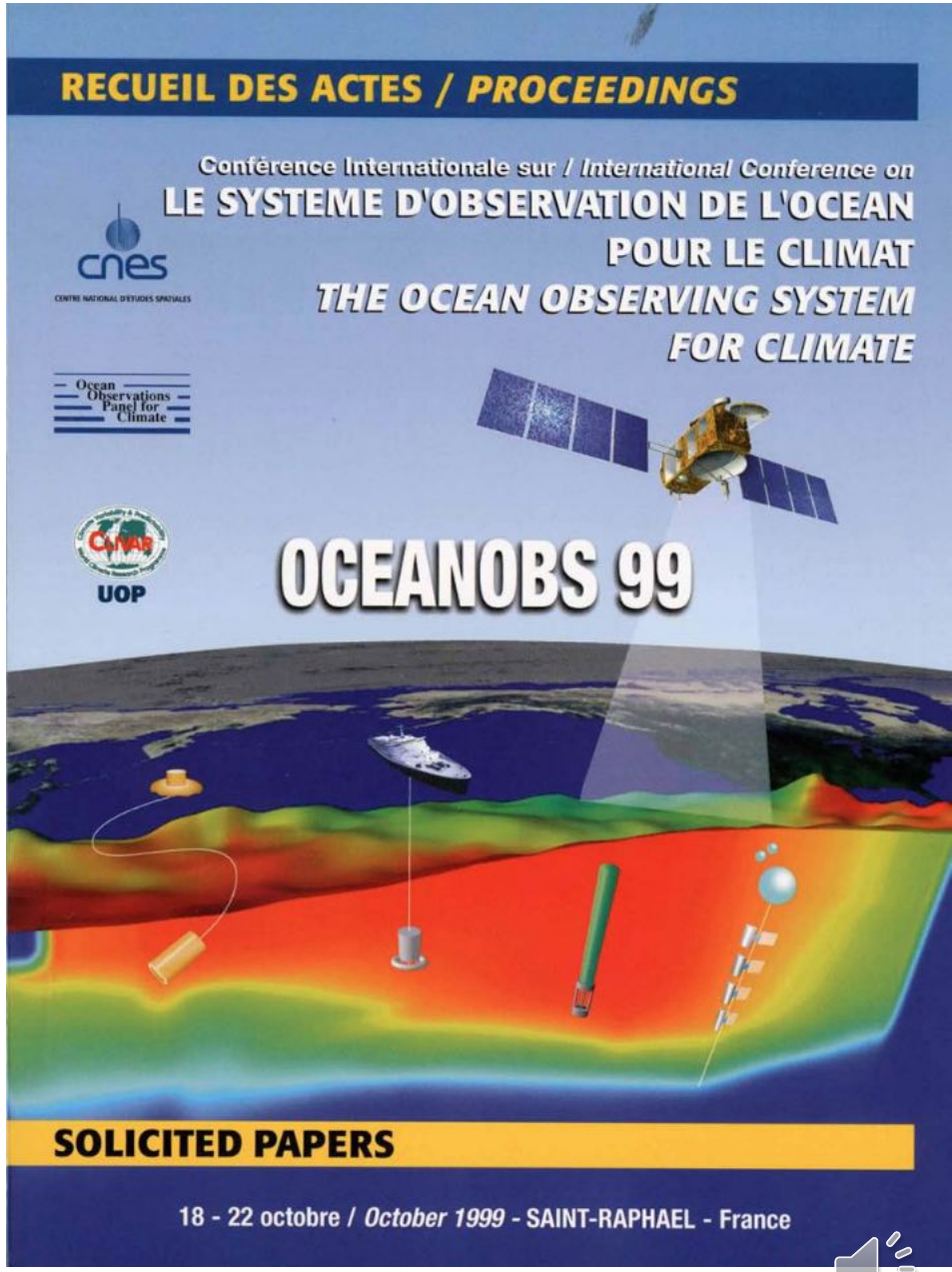




OceanSITES

At the international conference OceanObs ‘99 in St. Raphael, France (October 1999), oceanographers envisioned a global system of Eulerian observatories to become known as OceanSITES.

Uwe Send, Bob Weller et al. (1999), *Oceanographic Timeseries Observatories, OceanObs ’99*

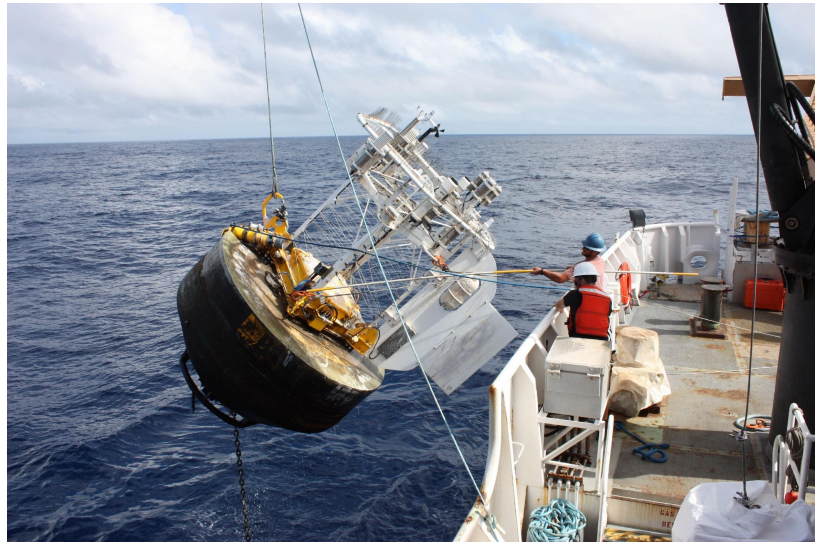


OceanSITES

Taking the pulse of the global ocean

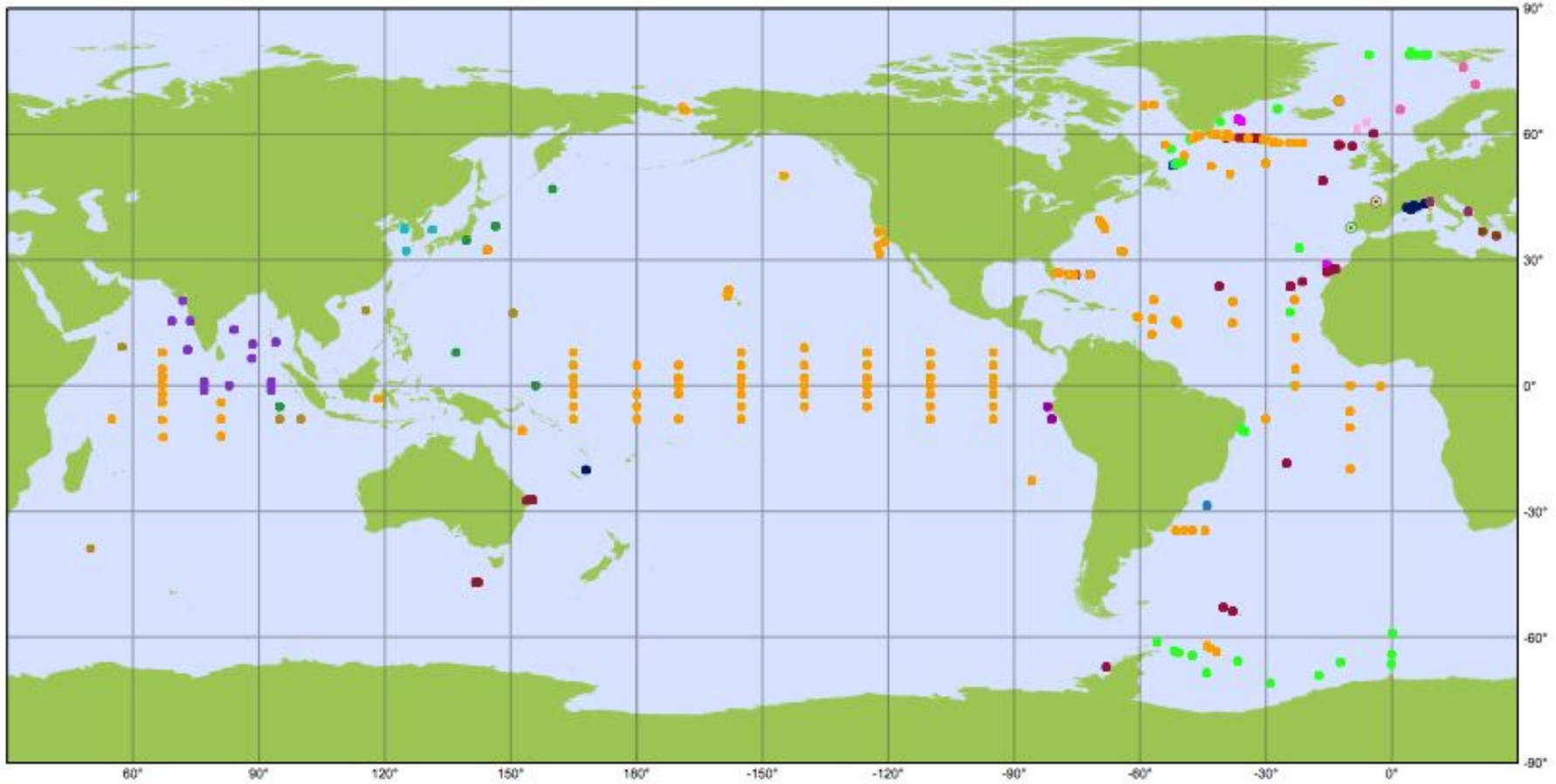
The mission of OceanSITES is to collect, deliver and promote the use of high-quality data from long-term, high-frequency observations at fixed locations in the open ocean. OceanSITES aim to collect multidisciplinary data worldwide from the full-depth water column as well as the overlying atmosphere.

Time series observations at critical or representative locations are one essential element of a global ocean observing system to complement a range of other approaches. They can provide: a unique view of the full temporal behavior of a system; accurate reference and long-time baseline data; and the maximum possible range of interlinked variables from the seafloor to the atmosphere while enabling shared resources.



OceanSITES

- Ultimately, a mooring, in its most crudest form, is nothing more than a rock with a rope with a surface or subsurface expression.
- It is the instruments that you deploy on the mooring that makes it interesting.
- It is the *“gold standard”* for making fixed point (Eulerian) ocean - atmosphere measurements.



OceanSITES

Platforms by country

May 2022

- AUSTRALIA (8)
- BRAZIL (1)
- CANADA (5)
- CHINA (7)
- DENMARK (6)
- EUROPE (3)
- FRANCE (6)
- GERMANY (43)
- GREECE (2)
- ICELAND (1)
- INDIA (15)
- ITALY (2)
- JAPAN (7)
- KOREA, REPUBLIC OF (27)
- NETHERLANDS (8)
- NORWAY (3)
- PERU (2)
- PORTUGAL (1)
- SPAIN (1)
- UK (49)
- USA (178)

OceanSITES

Generated by ocean-ops.org, 2022-06-02
Projection: Plate Carree (-150,0000)

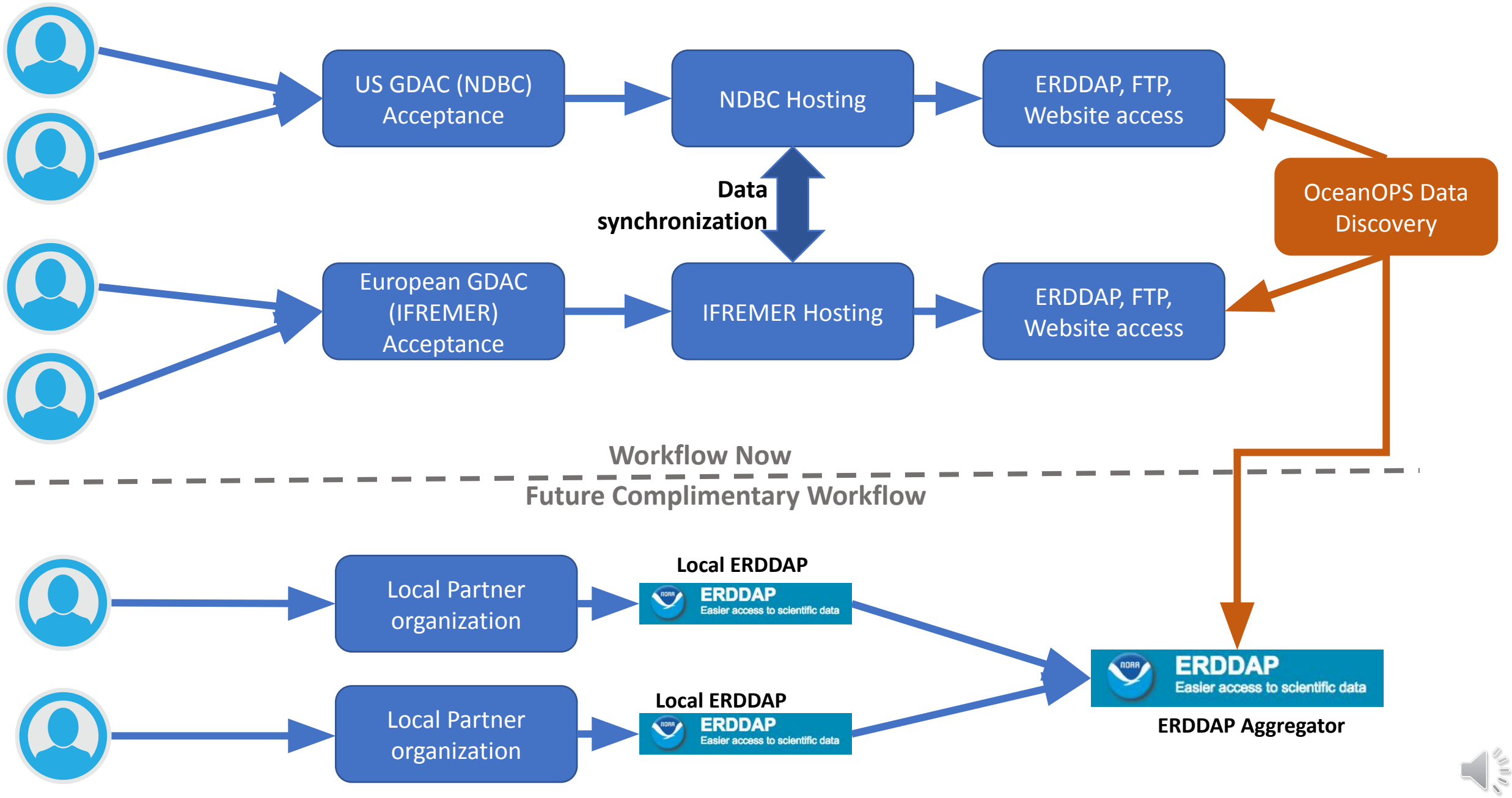
GOMO OceanSITES Stations

Station	First Deployment	Region	PI
California Current Ecosystem (CCE-1, CCE-2)	Nov 2008, Jan 2010	Southern California Current (CalCOFI Line 80)	U. Send / M. Lankhorst (SIO)
Kuroshio Extension Observatory (KEO)	June 2004	North Pacific Western Boundary Current	M. Cronin (PMEL)
Meridional Overturning Variability Experiment (MOVE)	January 2000	Northwest Tropical Atlantic	U. Send / M. Lankhorst (SIO)
Northwest Tropical Atlantic Station (NTAS)	March 2001	Northwest Tropical Atlantic	R. Weller / A. Plueddemann (WHOI)
Station Papa	June 2007	Northeast Pacific	M. Cronin (PMEL)
PIRATA (now NOAA/NWS)	10S, 10W on Sept 11, 1997	Tropical Atlantic	M. McPhaden (PMEL)
PIRATA Northeast Extension (PNE)	June 2006 – May 2007	Tropical Atlantic	G. Foltz (AOML)

GOMO OceanSITES Stations

Station	First Deployment	Region	PI
Southwest Atlantic MOC (SAM)	March 2009	Southwest Atlantic (34.5 S)	R. Perez / S. Dong (AOML)
Stratus	October 2000	Southwest Pacific Stratus deck	R. Weller / A. Plueddemann (WHOI)
Western Boundary Time Series (WBTS)	April 2004	Subtropical North Atlantic	M. Baringer (AOML)
Wood Hole Hawaii Ocean Time Series (WHOTS)	8/2004	North of Oahu, Hawaii	R. Weller / A. Plueddemann (WHOI)
Weddell Sea	1999	Southern Ocean	A. Gordon (LDEO)

OceanSITES Workflow: Present and Planned



OceanSITES Achievements

- 15+ years of modern moored records at Papa (50°N 145°W), extending historic ship-based time series dating back to 1949 (70+ year time series), making it one of the longest oceanographic and atmospheric records in the world.
- 20+ year time series at Stratus, NTAS; 17+ years at WHOTS; withheld, accurate surface meteorology and air-sea fluxes; merged data shared; uncertainties quantified.
- 18+ years of moored record from the only OceanSITES mooring (KEO 32°N 145°E) located within a western boundary current system. Observes typhoons, extratropical transitions, winter storms, eddies and strong currents, fronts, STMW formation, strong heat flux and CO2 uptake.
- About 40 years of quasi-continuous daily measurements of Florida Current volume transport with a submarine cable.
- 10 year time series of Atlantic Western Boundary Current transport and bottom temperatures at SAM.
- Quantified biases in air-sea fluxes in modern reanalyses (ERA5, NCEP2, MERRA2).

OceanSITES Impacts

- Established the need for improvements to atmospheric models and reanalyses that would improve their performance and value as source of ocean forcing.
- Quantified biases in CMIP6 models, setting context for their use.
- Observation-based climatologies with documented uncertainties provide benchmarks for use in climate studies and modeling.
- COARE serves as international standard for flux computations used for buoys, ships, satellites, and numerical models.
- OAFlux is a flagship flux product to support modeling and understanding of air-sea exchange and coupling.

OceanSITES Future Plans

- Engage with BSRN (Baseline Surface Radiation Network) and others to integrate ocean observing of surface radiation with land-based radiation observing.
- Work toward integration on surface buoys of critical measurements for improving fluxes, including DCFS (Direct Covariance Flux System), buoy motion and orientation, and surface waves.
- Ensure that measurements at key SAM sites can be obtained via automated datapod systems in the event that cruises are cancelled/postponed.
- Work toward implementing machine learning to increase the impact of in situ measurements on satellite-based air-sea flux estimates.
- Update obsolescent KEO and Papa systems (e.g. data acquisition system (TELOS), radiometers), and expand mooring capabilities to include DCFS (direct covariance flux system), and other sensors.
- Improve WBTS cable measurements by instrumenting a new recording system on the west side of the Florida Straits in West Palm Beach.
- Continue exploring alternative methods to measure the Florida Current volume transport using in situ and space-borne instrumentation.

OceanSITES Opportunities

- Evaluate new sensor and antifouling technologies.
- Partner with Indian and Chilean colleagues, technology transfers.
- Continue to welcome additional institutional collaborations and joint/ piggybacked projects.
- With older data systems becoming obsolete, there are opportunities to get involved at the ground-level engineering of new systems.

OceanSITES measurements are a cornerstone for documenting the ocean, improving ocean models, and providing ground-truth for satellite observing!

Acknowledgements

NOAA OAR Laboratories (AOML, PSL and PMEL)

NOAA OAR Cooperative Institutes (CICOES, CIMAS, CIMEAS and CINAR)

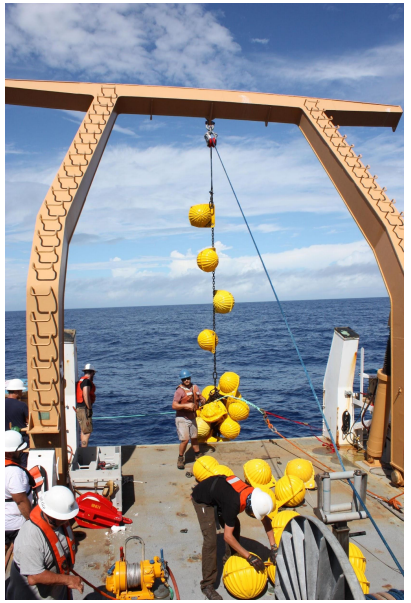
NOAA Administrative Offices

NOAA Office of Marine and Aviation Operations (OMAO)

OceanSITES Co-Chairs

International Colleagues

Team GOMO



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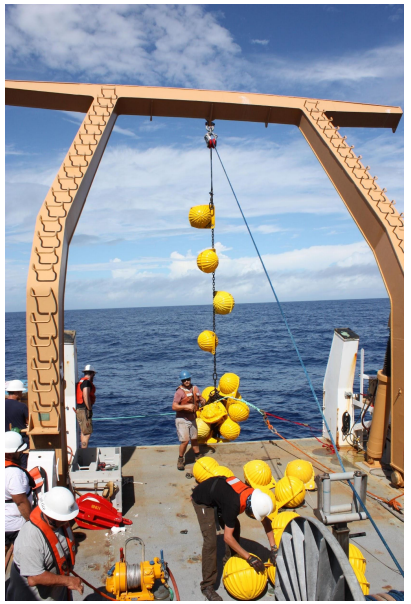

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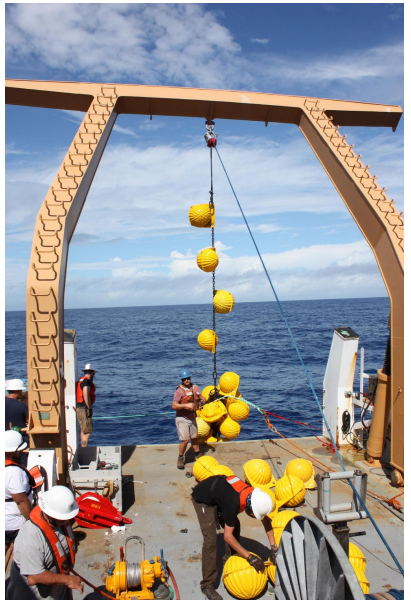

Global Ocean Monitoring and Observing
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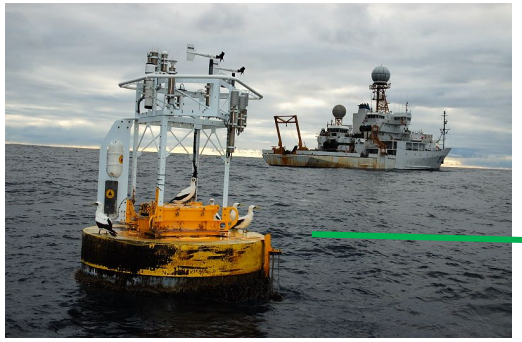
Additional Slides

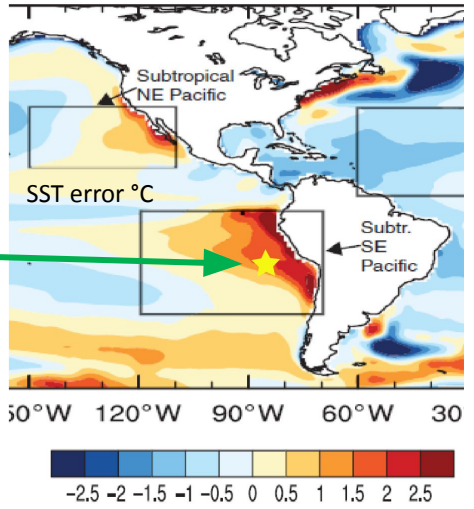
Stratus Ocean Reference Station

Weller and Plueddemann, WHOI

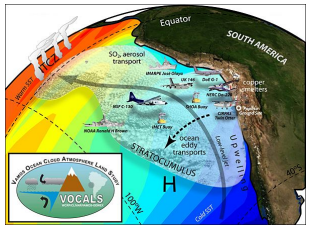
Partners: Fluxes (Fairall, PSL)**; Carbon** (PMEL); **Oxygen** (GEOMAR. Germany);
Chile (SHOA, U. Chile, U. Concepcion)

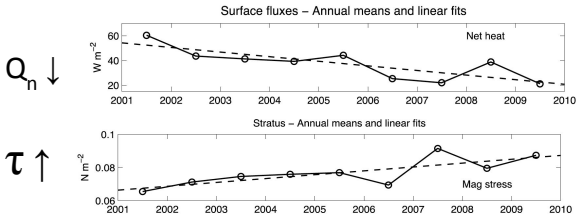
- Sampling a key region of persistent marine stratus clouds with basin-scale impacts
- Climate quality, withheld observations to understand large regional model errors
- Development of observation-based local climatology and anomalies
- Sole source of accurate surface meteorology and air-sea fluxes in Eastern S. Pacific
- Ground-truthing remote sensing, anchoring hybrid flux fields (e.g. OA Flux)
- Identifying ocean processes governing SST and mixed layer evolution
- Illuminating dynamics of the oxygen minimum zone





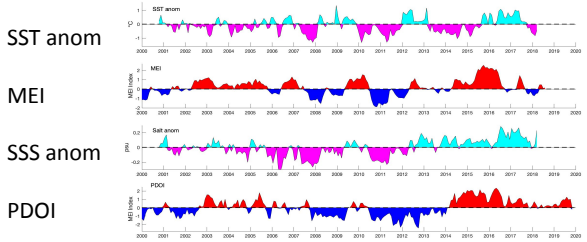
Stratus ORS (star), is located where CMIP models have strong SST bias (after Richter, 2015)



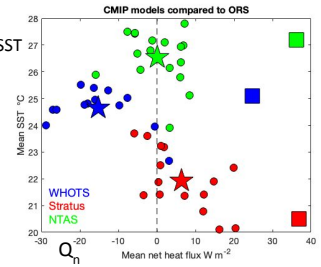


$Q_n \downarrow$

$\tau \uparrow$



CMIP6 SST and Q_n error



EPIC-2001: showed **uniqueness and climate impact of Chilean Stratus deck** region

Stratus ORS: first accurate air-sea fluxes in eastern S. Pacific leading to identification of model biases and showing that the ocean budget points to oceanic cooling and freshening processes

VOCALS REx: anchor process study with foci on model improvement, cloud physics, the role of ocean eddies**; identifies Stratus ORS as regionally representative**

Stratus ORS: 2000-2010**: decade of strengthening trade winds**, growing latent heat loss, decreasing net heat oceanic heat gain**;** improved heat budget; collaboration on **regional oxygen minimum zone dynamics**

Stratus ORS: instruments added to have **better resolution over depth** of cool, fresh subsurface mode water (ESPIW) and oxygen minimum zone, and to show vertical structure of eddies

Stratus ORS: 2011-2014: **weakening winds, PDO Index negative**; building the climatology of the Stratus ORS site from observations

Stratus ORS: **key mixed layer mixing process** associated with sags in Trade wind speed identified; **eddy transport of heat, freshwater, oxygen** quantified in joint work with GEOMAR

Stratus ORS: 2015-2020: PDO Index positive; **low frequency variability in SST and sea surface salinity reflecting ENSO and PDO signals**

Stratus ORS: 2000-2022 observations **quantify errors in modern reanalyses (ERA5, NCEP2, MERRA2) and CMIP6 models;** reaching out to Chilean colleagues on use of Stratus data in study of Chilean drought

Stratus

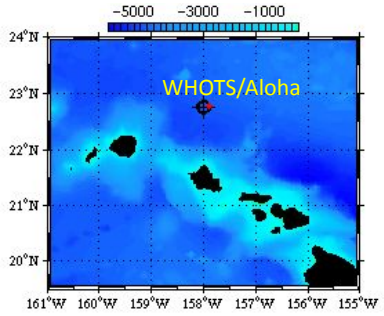
2000

2022+

WHOI Hawaii Ocean Time-series ORS

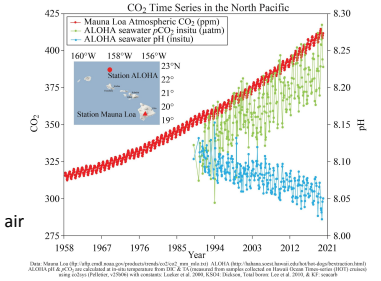
Weller and Plueddemann, WHOI

Partners: Hawaii Ocean Time-series (A. White, J. Potemra, R. Lukas**)** , **Carbon Group** (PMEL), **UH students**



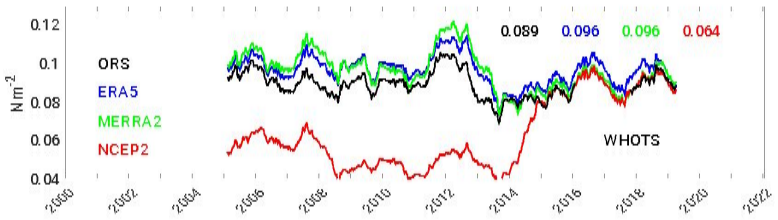
WHOTS, deep water north of Oahu

- a mid-Pacific flux reference site pairing with long-running Maua Loa atmospheric CO_2, HOT multi-disciplinary shipboard sampling, Aloha Cabled Observatory (ACO)
- climate quality withheld observations to understand regional model errors
- supplying the atmospheric forcing and physical oceanographic time series for HOT
- test bed for mixed layer model development, improved mixing, albedo, and optical absorption codes developed
- characterization of thermohaline anomalies, their relation to regional hydrological cycle and ocean transports, and as context for HOT biochemical studies
- combination of WHOTS and ACO deep T/S sampling provide key deep observing testbed

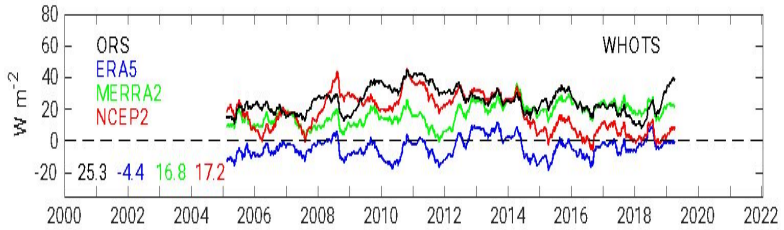


Keeling curve, Aloha air and water CO_2

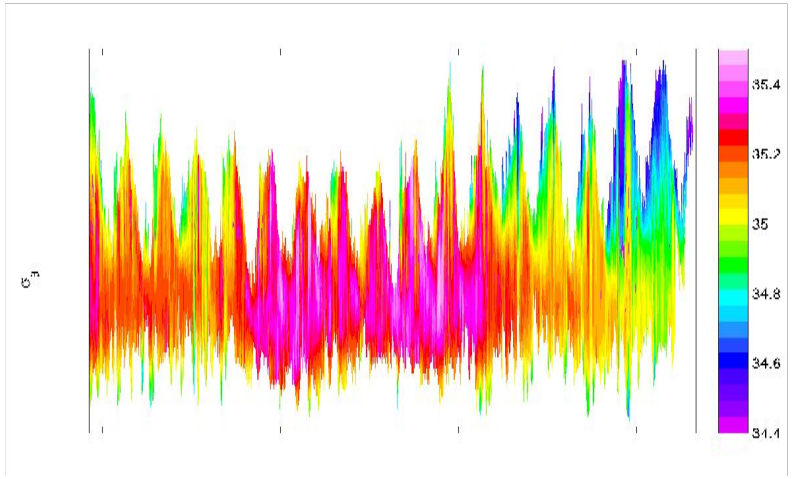
Low-passed stress and record means



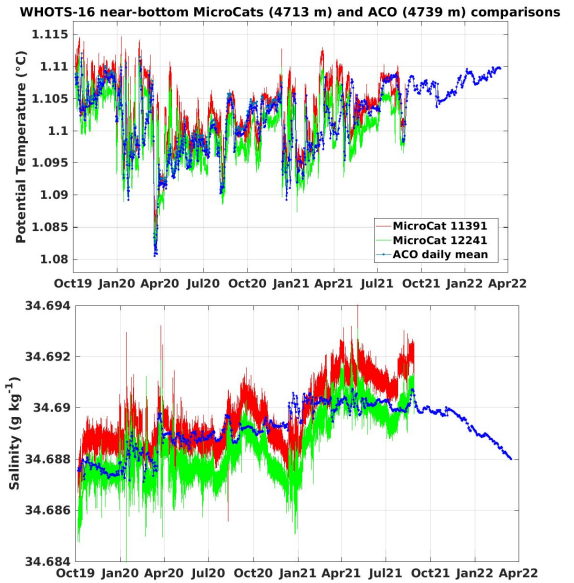
Assessing modern reanalyses: top – NCEP2 large underestimate of wind stress prior to 2015; bottom – ERA5 net heat flux biases 30 W m^{-2} low. Surprising temporal variability in quality of reanalyses



Low-passed Q_n and record means



Low frequency modulation of thermohaline structure. Notable increase in water column salinity 2008-2016 and narrower range of potential density followed by freshening and wider range of density across observed depths. Forcing functions under study – regional hydrological cycle and low-frequency variability in ocean transports.



Overplotted WHOTS and ACO deep temperatures (top) and salinity (bottom). Findings – variability I T and S, few models provide realistic deep temperatures, lessons learned for DOOS

Northwest Tropical Atlantic ORS (NTAS)

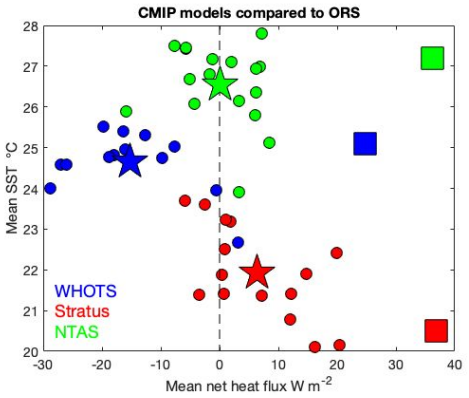
Plueddemann and Weller, WHOI

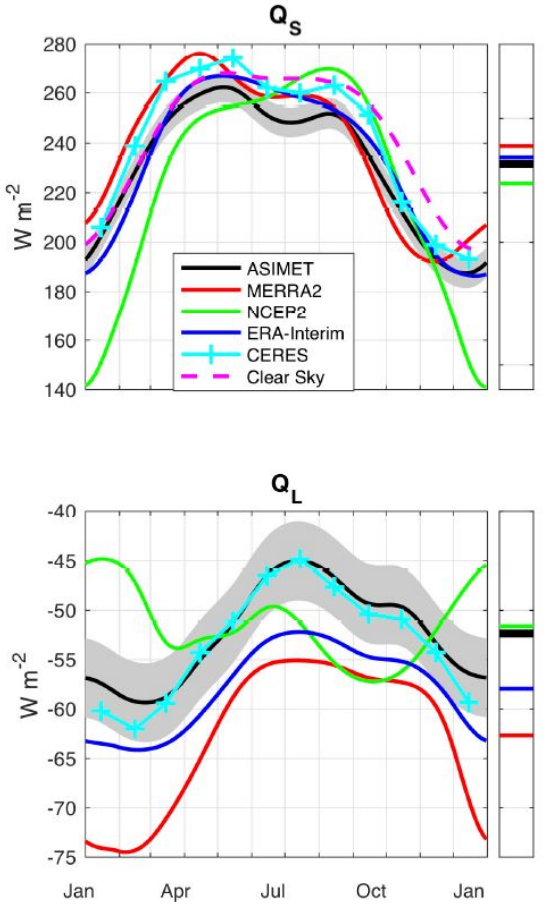
- Established (2001) to quantify air-sea exchanges in a region with strong SST and flux signatures
- Collaborative field work with MOVE, PSL, NDBC
- Real-time telemetry of upper ocean T, S and currents
- Climate-quality withheld observations to understand regional model errors, compare with NWP and satellite
- Development of observation-based local climatology and anomalies
- Highlights:
  - NWP struggle to reproduce annual cycle of radiative fluxes in the NW tropical Atlantic
  - Relationship of radiative fluxes to cloud cover and impact on SST

Joint ops with MOVE

Joint ops with NDBC

Observations quantify errors in reanalyses (ERA5, NCEP2, MERRA2) and CMIP6 models

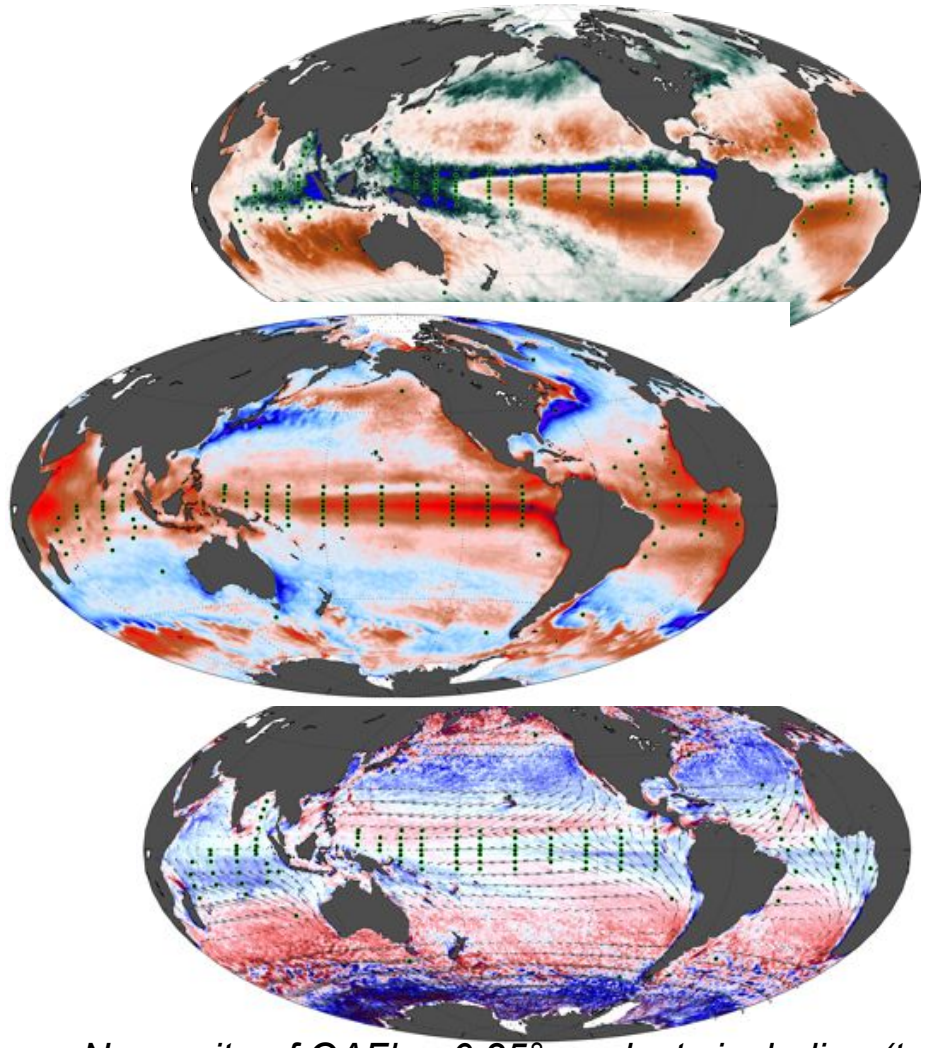




Annual cycle of shortwave (Qs) and longwave (Ql) flux at NTAS. Observed (black) with uncertainty (shaded) compared to MERRA-2 (red), NCEP-2 (green), ERA-Interim (blue). From Bigorre and Plueddemann (2021).

WHOI Objectively Analyzed air-sea Fluxes (OAFlux)

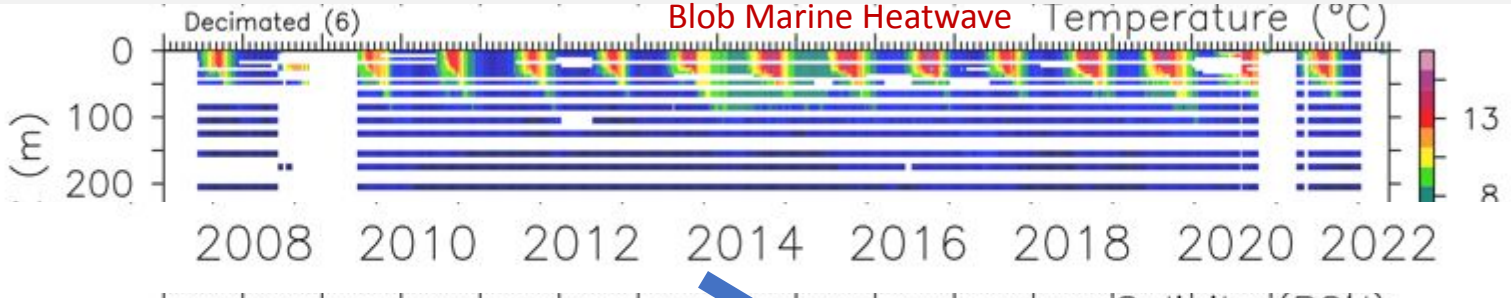
- Producing high-quality climate data records of air-sea heat, freshwater, and momentum fluxes by anchoring product validation to global moored buoy measurements.
- A flagship flux product that supports the needs for ocean and climate communities in areas of the global energy budget, water cycle, atmosphere and ocean circulation, climate change and variability.
- Essential in situ database: OceanSITES surface data
- **FY17-FY21 highlights:** Used OAFlux products to evaluate the uncertainties in the global water cycle budget (Yu et al. 2017; Dorigo et al. 2021) and surface heat budget (Wen et al. 2017; Yu et al. 2019; Beal et al. 2020; Phillips et al. 2021); developed new retrieval algorithms (Yu and Jin 2018); examined key issues in ocean-surface heat budget closure (Yu 2019); quantified the water cycle amplification rate (Yu et al. 2020); detected long-term trends in water mass in the Atlantic (Yu et al. 2018); analyzed decadal



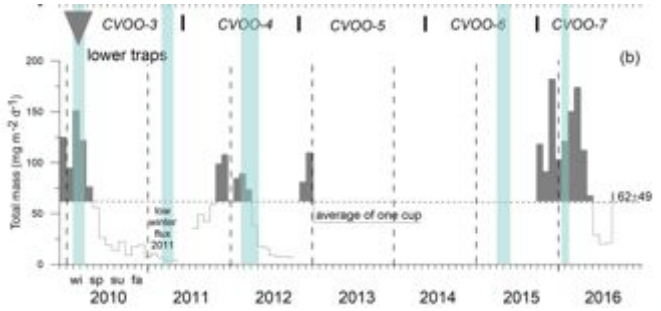
New suite of OAFlux-0.25° products including (top to bottom) surface freshwater, heat, and wind stress and curl, developed through leveraging funding support of NASA MeaSUREs.

Nations time series data for global needs - OceanSITES

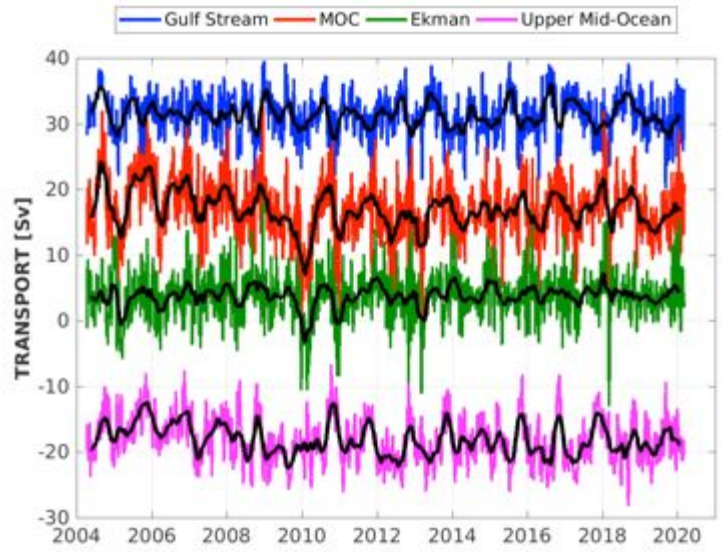
15 years PAPA upper ocean temperature evolution

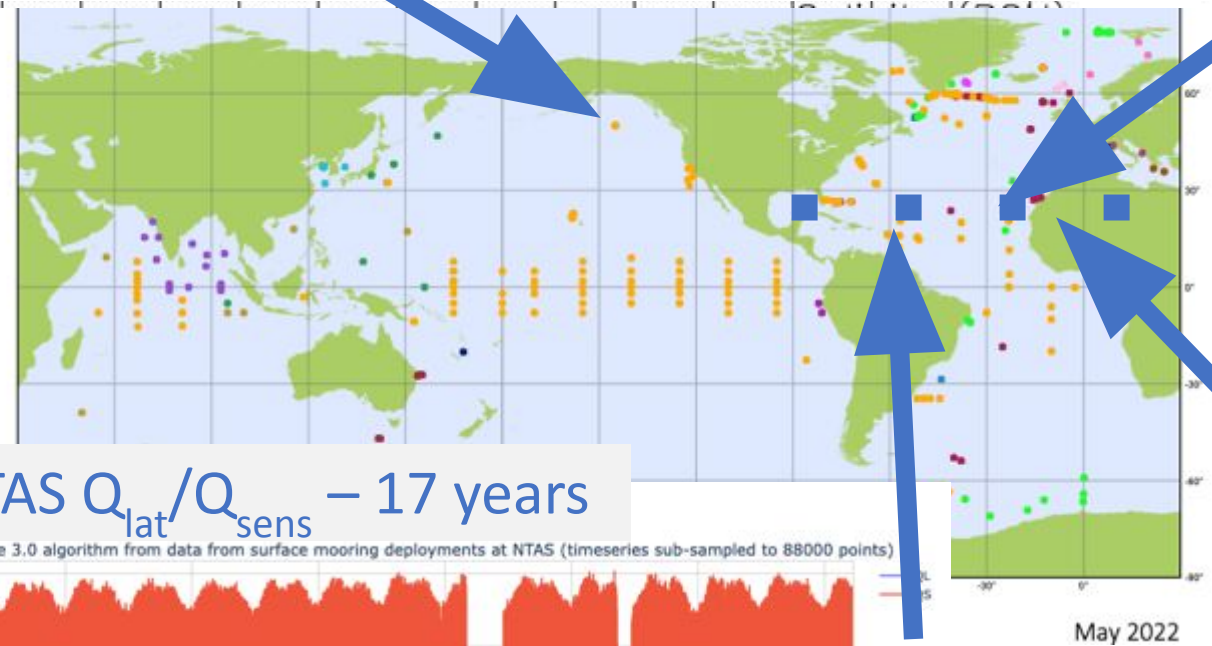


10 years Particle fluxes at CVOO

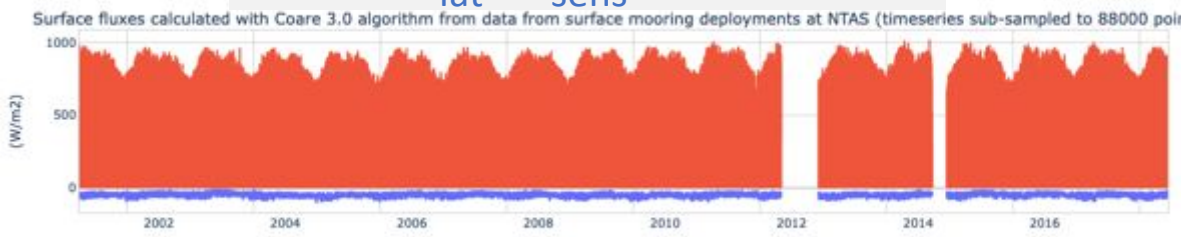


16 years Overturning strength



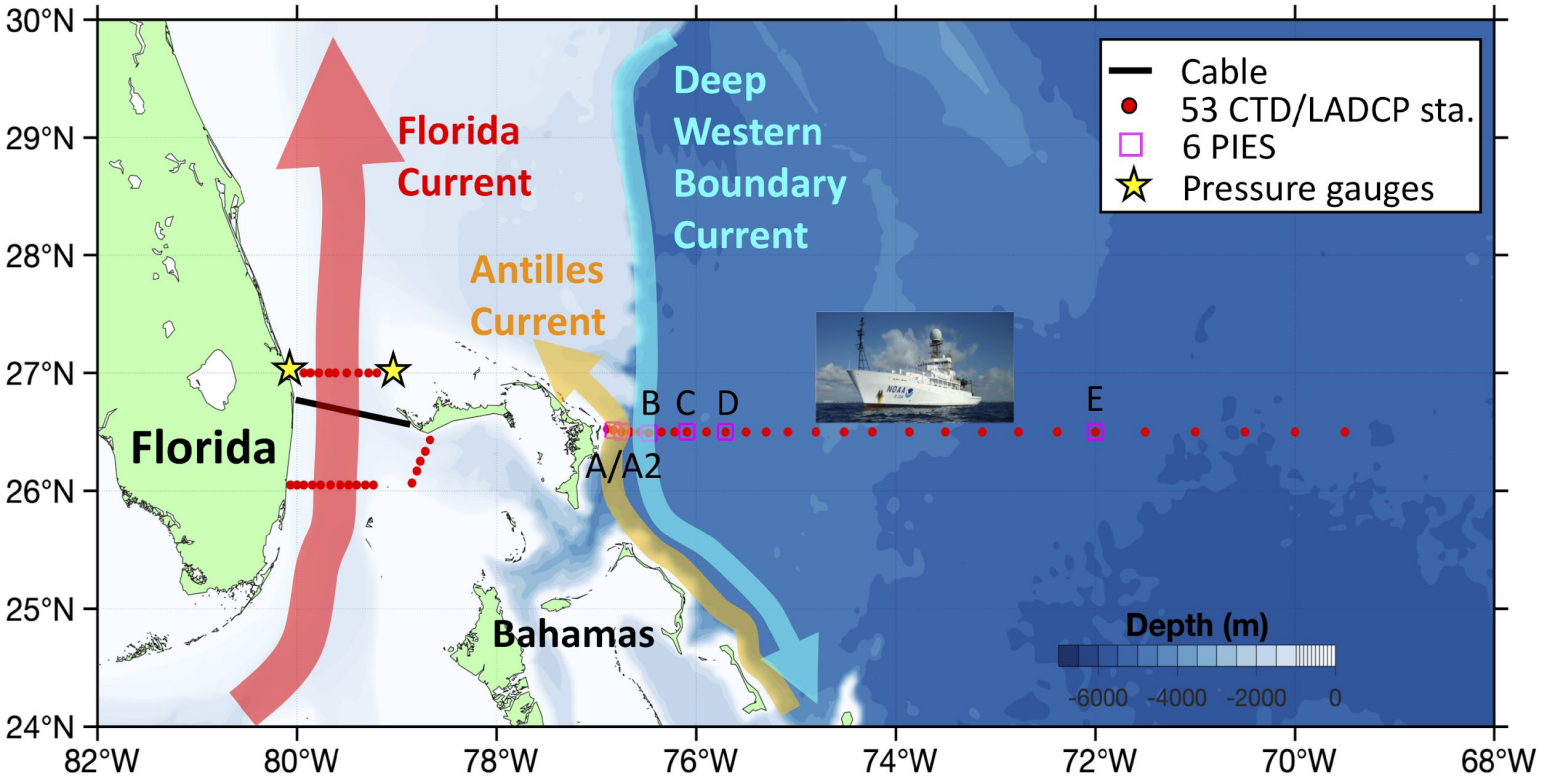


NTAS Q_{lat}/Q_{sens} – 17 years



Western Boundary Time Series (WBTS)

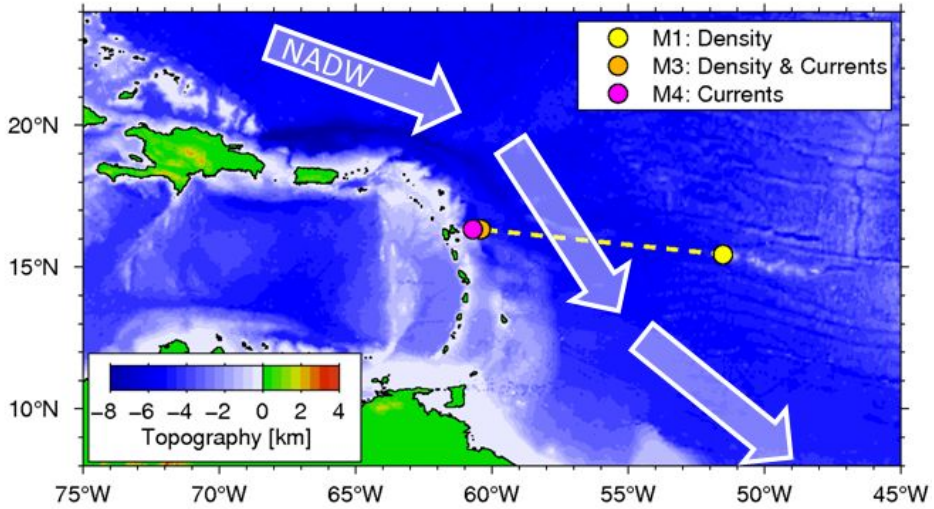
- Monitoring changes in western boundary current transports and water mass properties 26.5°N.
- Serving as a western boundary endpoint of an international AMOC monitoring system (RAPID-MOCHA-WBTS) at 26.5°N.
- Partners: RSMAS/University of Miami (USA), National Oceanographic Centre (UK)



FY17-FY21 highlights: WBTS submarine cable, pressure gauge, cruise, PIES mooring, and satellite altimetry data used to produce

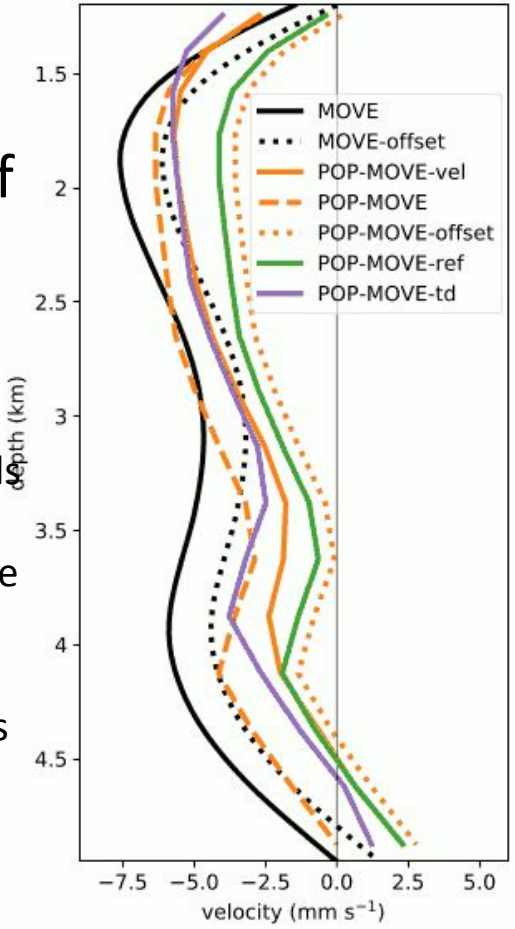
- time series of Florida Current, Deep Western Boundary Current, Antilles Current transport, as well as sections of temperature, salinity, oxygen, and meridional velocity at 26.5°N (Szuts & Meinen, 2017; Meinen et al., 2019; Volkov et al., 2020; Meinen et al., 2021);
- AMOC volume and heat transports (e.g., Frajka-Williams et al., 2021);
- impact of the variability of Florida Current on coastal sea level (Domingues et al., 2018, 2019);
- links between the AMOC and sea level (Volkov et al., 2019); and
- detect long-term changes in the AMOC (Smeed et al., 2018; Moat et al., 2020)

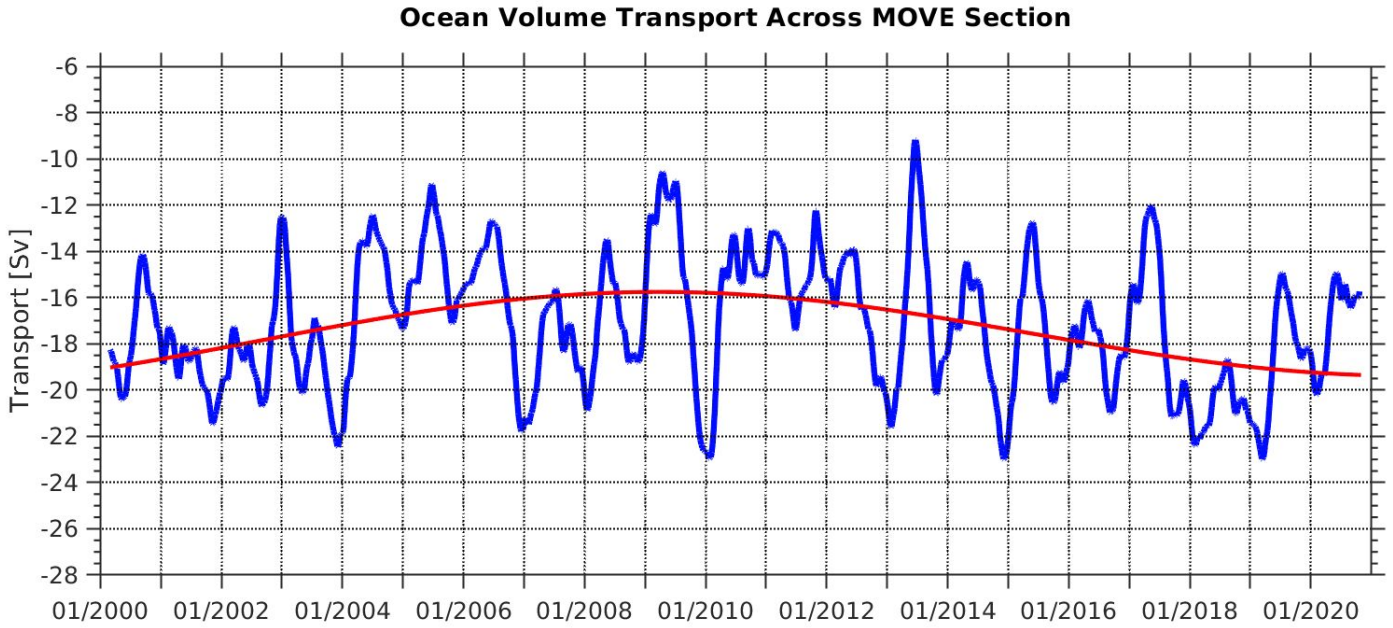
MOVE at 16°N (Meridional Overturning Variability Experiment)



- Observing the cold, southward limb of AMOC east of the Caribbean since 2000
- Accomplishments and strengths:
  - Time series now long enough to show decadal trends and variability
  - Observational assumptions validated against satellite gravimetry observations as well as numerical observations

moorings and long service intervals
ational costs

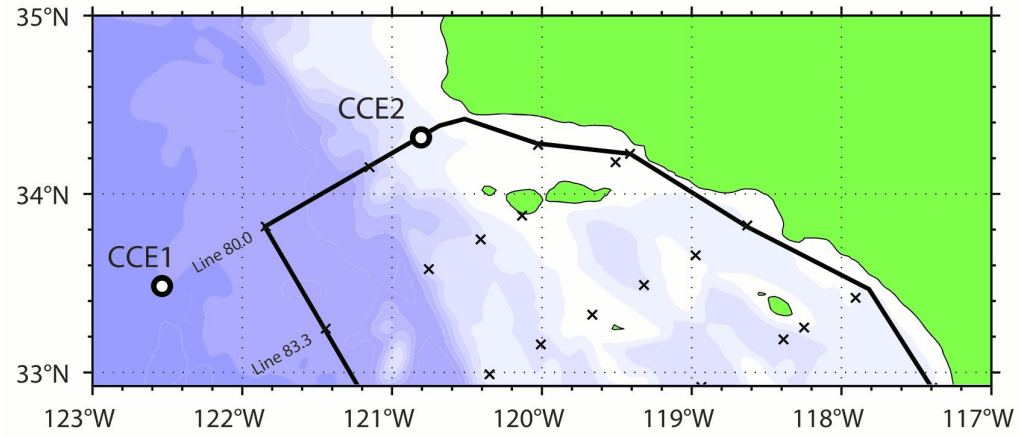


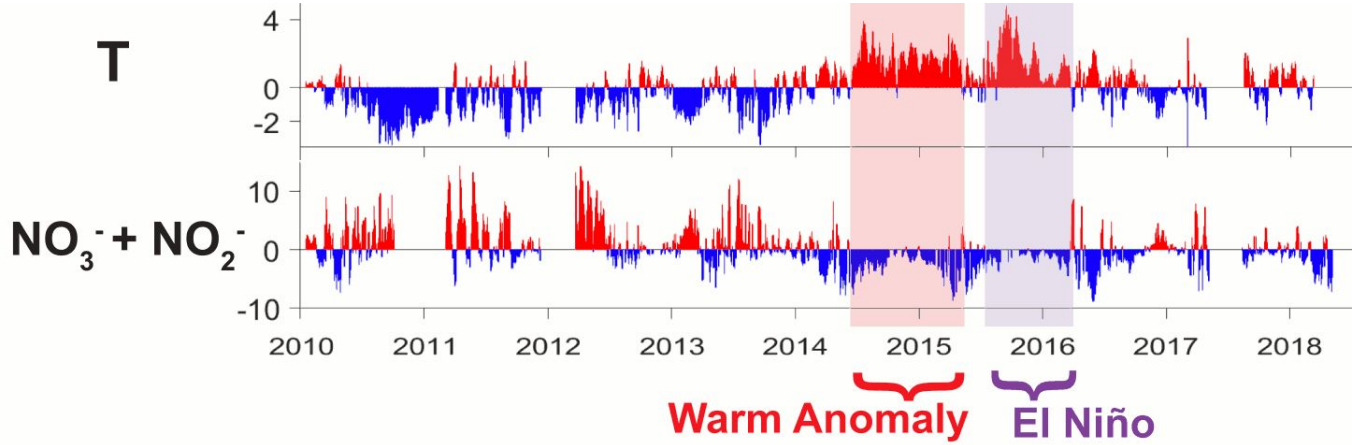


New in 2022:
Reprocessed salinity data, improving agreement with observations at other latitudes (important step towards a basin-wide understanding of AMOC)

Acknowledgements: MOVE was supported by NOAA GOMO (and the German BMBF in earlier years). Figures adapted from: Send et al. (GRL, 2011); Danabasoglu et al. (GRL, 2021).

CCE Moorings (California Current Ecosystem)

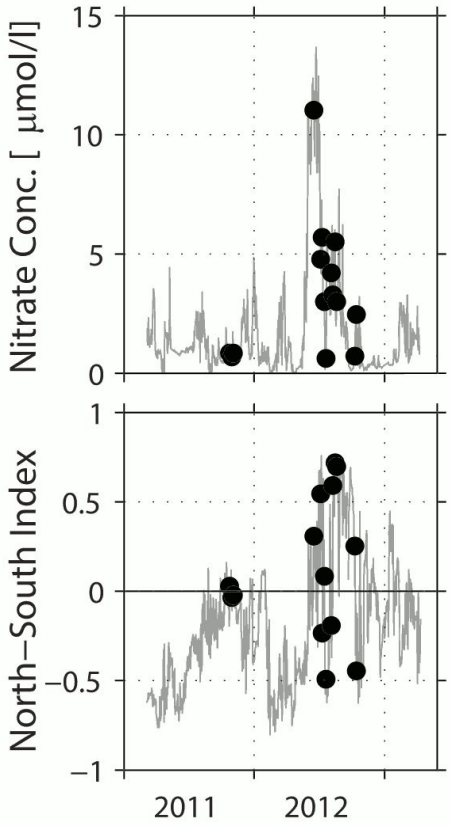




Observing biological and physical processes in the Southern California Current with two moorings, each with a multi-disciplinary sensor suite

Examples from Lilly et al., 2019:

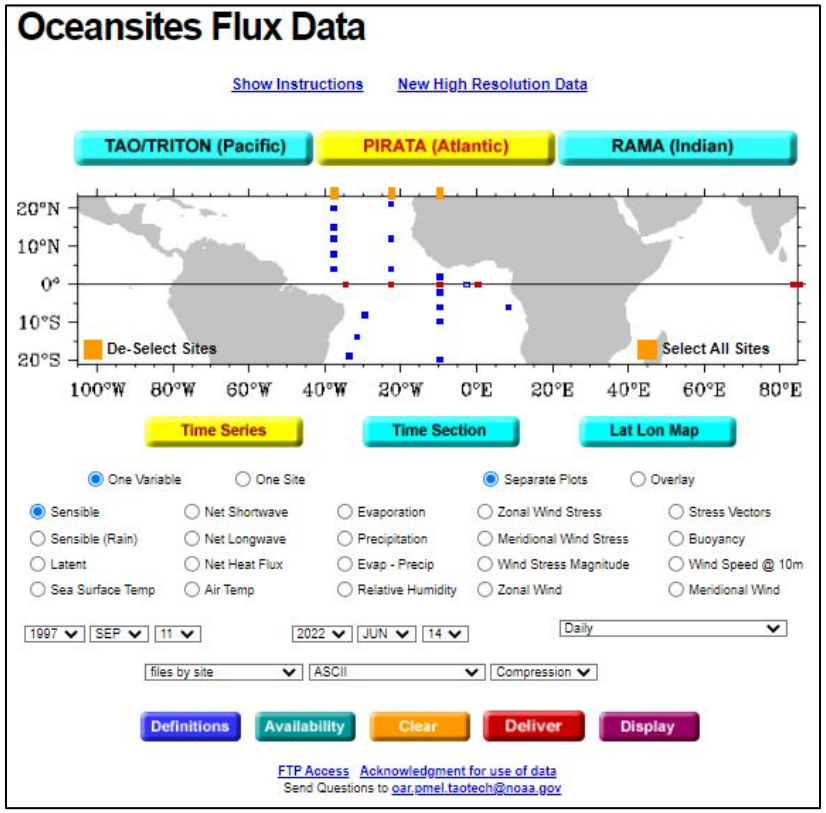
- Map (top left) shows locations of CCE1 and CCE2 moorings
- Strong signatures of 2014/15 warm anomaly and subsequent El Niño in temperature, and below-average nutrient concentrations (top right, both showing anomalies from CCE2 at 16 m depth)
- Warm anomaly and El Niño associated with elevated biomass of planktonic mollusc species (data from x stations on map, not shown)
- Elevated nutrient concentrations at CCE1 (right) can be caused by advection of “southern” water masses (N-S index positive, lower right) from near the coast (black dots showing instances when surface currents can be traced back to the shelf edge)
- **Take-home message: Concurrent long-term observations of biological and physical parameters reveal how the ecosystem is affected by the physical environment.**



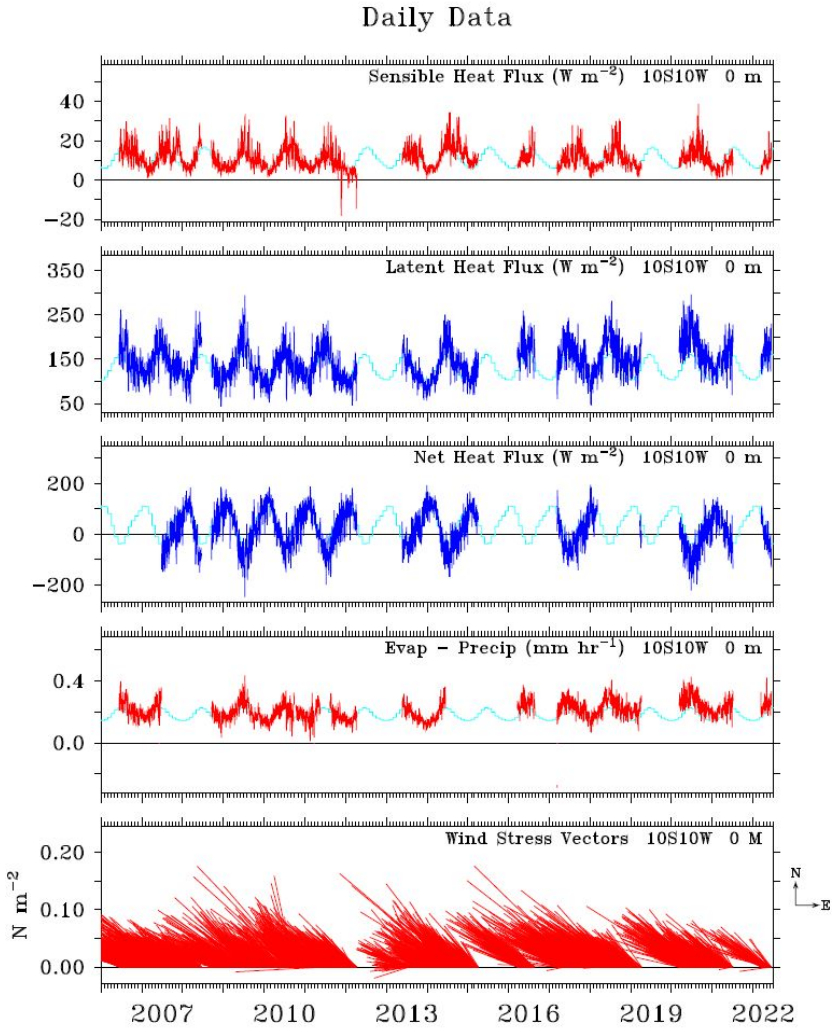
Acknowledgements: MOVE was supported by NOAA GOMO, OAP, and through in-kind contributions from SWFSC. Figures adapted from Lilly et al., 2019.

Dissemination of OceanSITES Flux Long Time-Series Data

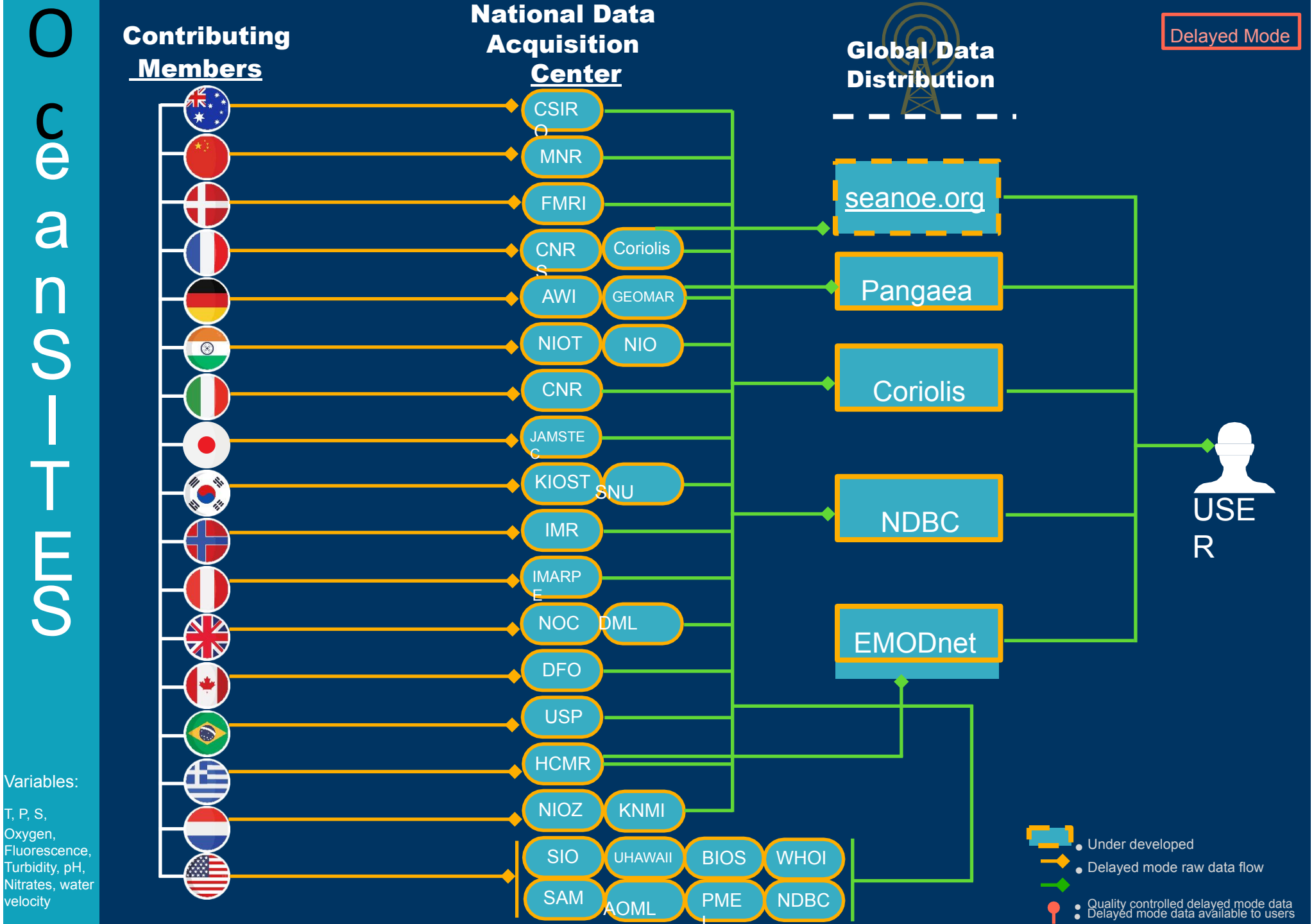
- Public display and delivery of OceanSITES flux data from moored buoys in PIRATA, RAMA, and TAO.
- Long time-series spanning decades.
- Partners: France, Brazil, Germany, India, Indonesia, South Korea, Japan, China
- **FY17-FY21 highlights:** High-resolution (hourly) flux data available for public access. Past successes have argued for expansion of flux sites: Foltz et al. (2019; TAOS); Beal, et al. (2020; IndOOS); Smith et al. (2019; TPOS-2020)



Data access for download and/or display at: https://www.pmel.noaa.gov/gtmba/data-access/flux



Web-generated flux data figures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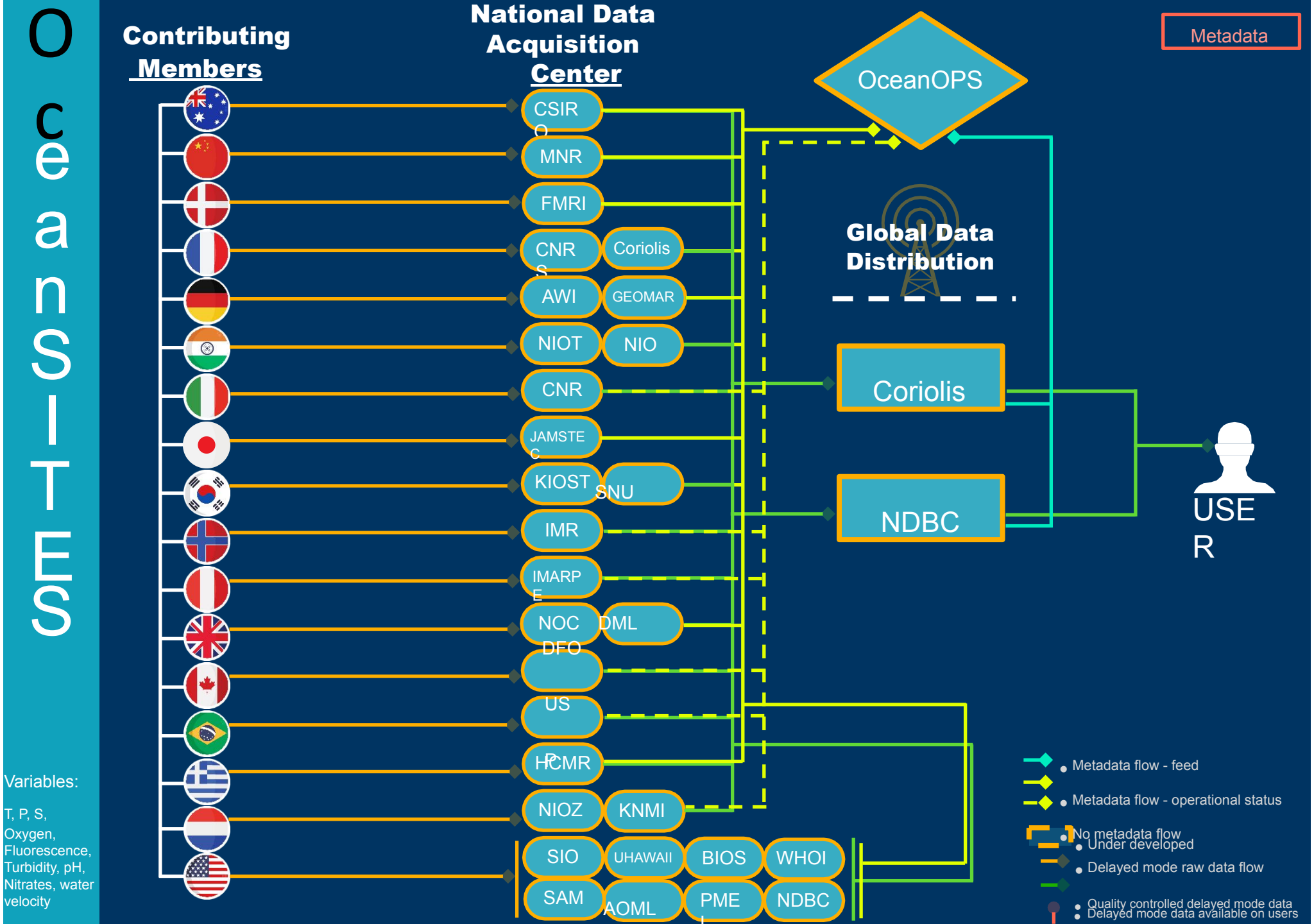
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OceanSITES Achievements

- 20+ year time series at Stratus, NTAS; 17+ years at WHOTS; withheld, accurate surface meteorology and air-sea fluxes; merged data shared; uncertainties quantified.
- Produced observation-based climatologies at Stratus, NTAS and WHOTS.
- Deep temperature/salinity time series, 8+ years available for Stratus, NTAS and WHOTS.
- Quantified biases in air-sea fluxes in modern reanalyses (ERA5, NCEP2, MERRA2) in Trade wind regions; found temporal variability in reanalyses' performance.
- Developed and maintained the COARE suite of bulk models of air-sea fluxes.
- Developed and maintained 60+ year gridded global analysis of air-sea fluxes and flux-related surface meteorology with uncertainty analysis provided.
- Utilized air-sea measurements from 150+ moored buoys to calibrate and validate the project products.
- Developed buoy-based satellite retrieval algorithms for improved estimates of air temperature and humidity.
- 15+ years of modern moored records at Papa (50°N 145°W), extending historic ship-based time series dating back to 1949 (70+ year time series), making it one of the longest oceanographic and atmospheric records in the world.
- 18+ years of moored record from the only OceanSITES mooring (KEO 32°N 145°E) located within a western boundary current system. Observes typhoons, extratropical transitions, winter storms, eddies and strong currents, fronts, STMW formation, strong heat flux and CO2 uptake.
- About 40 years of quasi-continuous daily measurements of Florida Current volume transport with a submarine cable.
- Reprocessed salinity data, improving agreement with observations at other latitudes (an important step towards a basin-wide understanding of AMOC).

OceanSITES Impacts

- Established the need for improvements to atmospheric models and reanalyses that would improve their performance and value as source of ocean forcing.
- Quantified biases in CMIP6 models, setting context for their use.
- Observation-based climatologies with documented uncertainties provide benchmarks for use in climate studies and modeling.
- Deep temperature/salinity observations and the technical challenges found associated with the effort provided prototypical case study for DOOS (Deep Ocean Observing Strategy).
- COARE serves as international standard for flux computations used for buoys, ships, satellites, and numerical models.
- 10 year time series of Atlantic Western Boundary Current transport and bottom temperatures at SAM.
- OAFlux is a flagship flux product to support modeling and understanding of air-sea exchange and coupling.
- OAFlux has served as a standard evaporation product in support of satellite ocean salinity and water cycle missions.
- OAFlux provided a baseline for comparison for groups developing alternate air-sea flux products from satellite and in situ observations.
- Over 70 publications have used Papa or KEO OceanSITES mooring data (2017 - 2021).
- The WBTS data is used to calculate the MOC at 26.5N in the Atlantic.
- The Florida Current cable data and the MOC data are used to validate ocean and climate models.
- Concurrent long-term observations of biological and physical parameters reveal how the CCE is affected by the physical environment.

OceanSITES Future Plans

- Engage with BSRN (Baseline Surface Radiation Network) and others to integrate ocean observing of surface radiation with land-based radiation observing.
- Improved laboratory calibration of incoming shortwave radiometers
- Work toward integration on surface buoys of critical measurements for improving fluxes, including DCFS (Direct Covariance Flux System), buoy motion and orientation, and surface waves.
- Add interdisciplinary EOVs (Essential Ocean Variables) such as Chl, oxygen, pH and seawater optical properties.
- Ensure that measurements at key SAM sites can be obtained via automated datapod systems in the event that cruises are cancelled/postponed.
- Work toward implementing machine learning to increase the impact of in situ measurements on satellite-based air-sea flux estimates.
- Update obsolescent KEO and Papa systems (e.g. data acquisition system (TELOS), radiometers), and expand mooring capabilities to include DCFS (direct covariance flux system), and other sensors.
- Work with BSRN (baseline surface radiation network) to improve ocean-based radiation measurements; potentially develop a PMEL radiation testing facility.
- Improve WBTS cable measurements by instrumenting a new recording system on the west side of the Florida Straits in West Palm Beach.
- Continue exploring alternative methods to measure the Florida Current volume transport using in situ and space-borne instrumentation.

OceanSITES observing network

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high-quality data from long-term, high-frequency observations at fixed locations in the open ocean

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Technical summary TF Stocker, D Qin, GK Plattner, LV Alexander, SK Allen, NL Bindoff, ... Climate change 2013: the physical science basis. Contribution of Working …	5121 *	2013
Ocean Acidification: The Other CO_2 Problem SC Doney, VJ Fabry, RA Feely, JA Kleypas Annual review of marine science 1, 169-192	4149 *	2009
Photosynthetic rates derived from satellite-based chlorophyll concentration MJ Behrenfeld, PG Falkowski Limnology and oceanography 42 (1), 1-20	2886	1997
Archaeal dominance in the mesopelagic zone of the Pacific Ocean MB Karner, EF DeLong, DM Karl Nature 409 (6819), 507-510	1609	2001
Prochlorococcus, a Marine Photosynthetic Prokaryote of Global Significance F Partensky, WR Hess, D Vaulot Microbiology and molecular biology reviews 63 (1), 106-127	1494	1999

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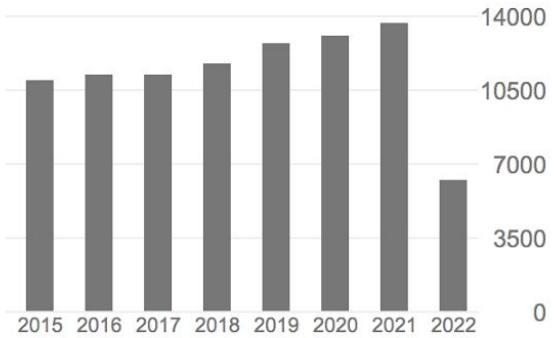


Co-authors VIEW ALL

Robert A. Weller
Woods Hole Oceanographic Insti…

David Karl
University of Hawaii

EuroSea/OceanPredict workshop (June 29 – July 1, 2022)

Aloha Bob (Weller),

The agenda is interesting, with some views towards how best to use high-resolution (in time and/or space) observations in constraining ocean models (e.g. Andrew Moore's presentation.) Your presentation both* ***reminds ocean modelers that the forcing fields they use from atmospheric reanalyses are not perfect, and underscores the value of long, consistent, well-calibrated near-surface observations.*** *The Ocean Reference Stations provide key benchmarks not only for atmospheric reanalyses, but also for ocean reanalyses.*

Thanks,
Roger (Lucas, U. Hawaii)

*Andrew Moore (UC Santa Cruz), *Forecast Sensitivity-based Observation Impact (FSOI) and Forecast Sensitivity to Observations (FSO) in an Analysis-Forecast System of the California Current Circulation.*

GOMO OceanSITES Program Reviews

Transport Moorings

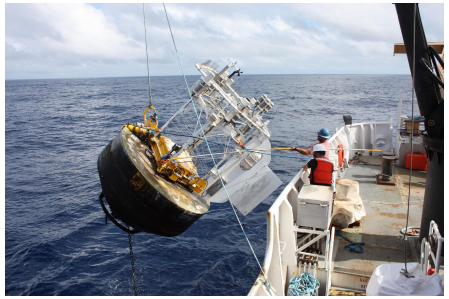
(October 2017, AOML, Miami, FL)

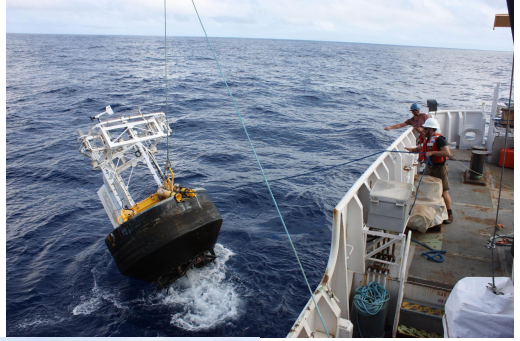
- SAM
- MOVE
- WBTS

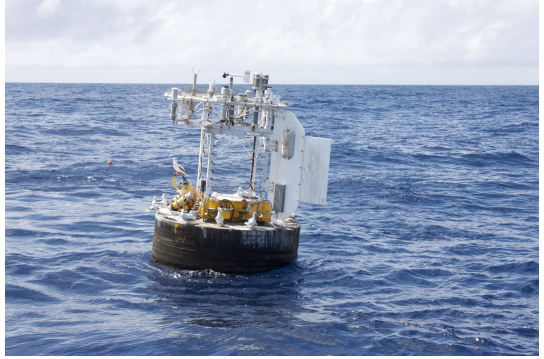
A/S Flux and Biogeochemical Moorings

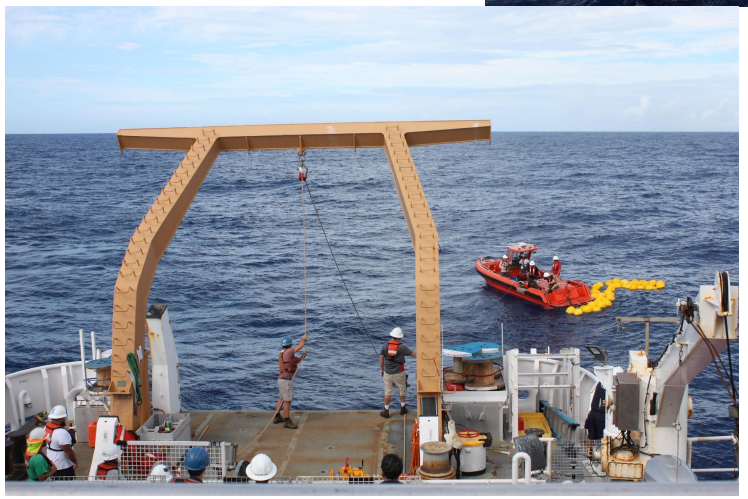
(December 2017, SIO, La Jolla, CA)

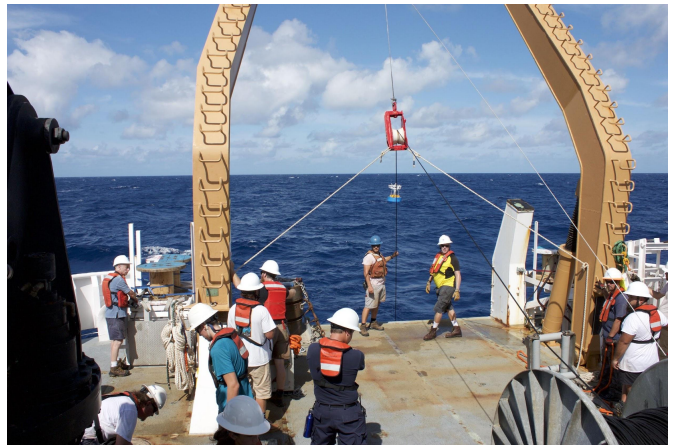
- NTAS
- Stratus
- WHOTS
- CCE
- KEO
- Papa

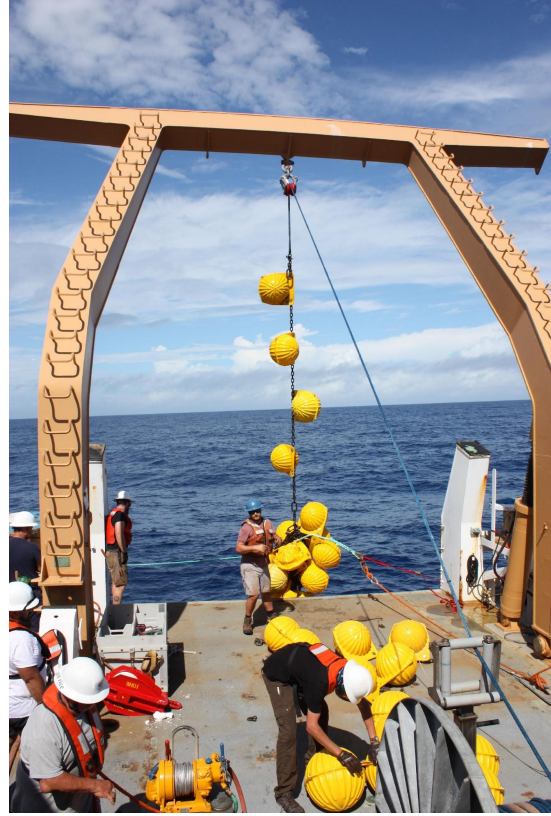


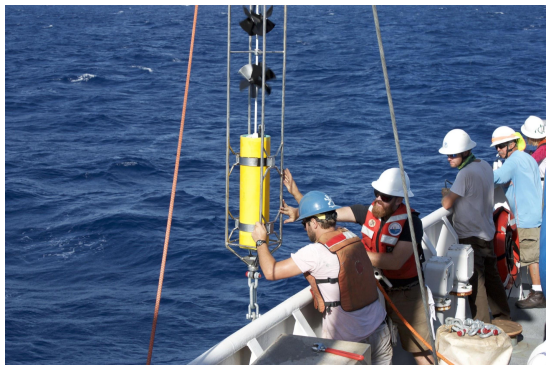










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